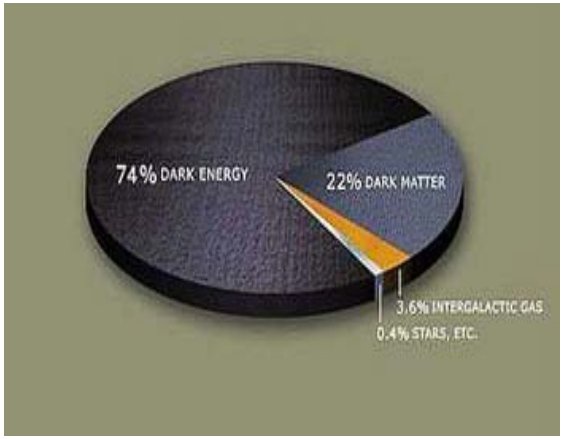
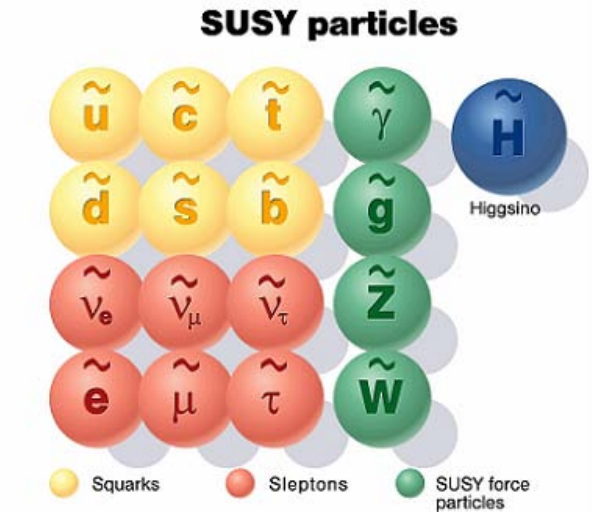
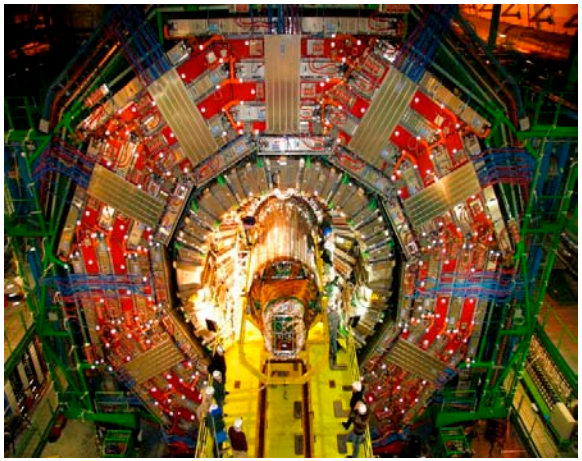
Karlsruher Institut für Technologie

Where is SUSY?

Institut für Experimentelle Kernphysik







Researchers failed to find evidence of so-called "supersymmetric" particles, which many physicists had hoped would plug holes in the current theory.

There's a certain amount of worry that's creeping into our discussions"

If supersymmetric particles exist, B-mesons ought to decay far more often than if they do not exist.
CDF found hint, but LHCb and CMS failed to find this effect.

Where is SUSY? Where do we stand?

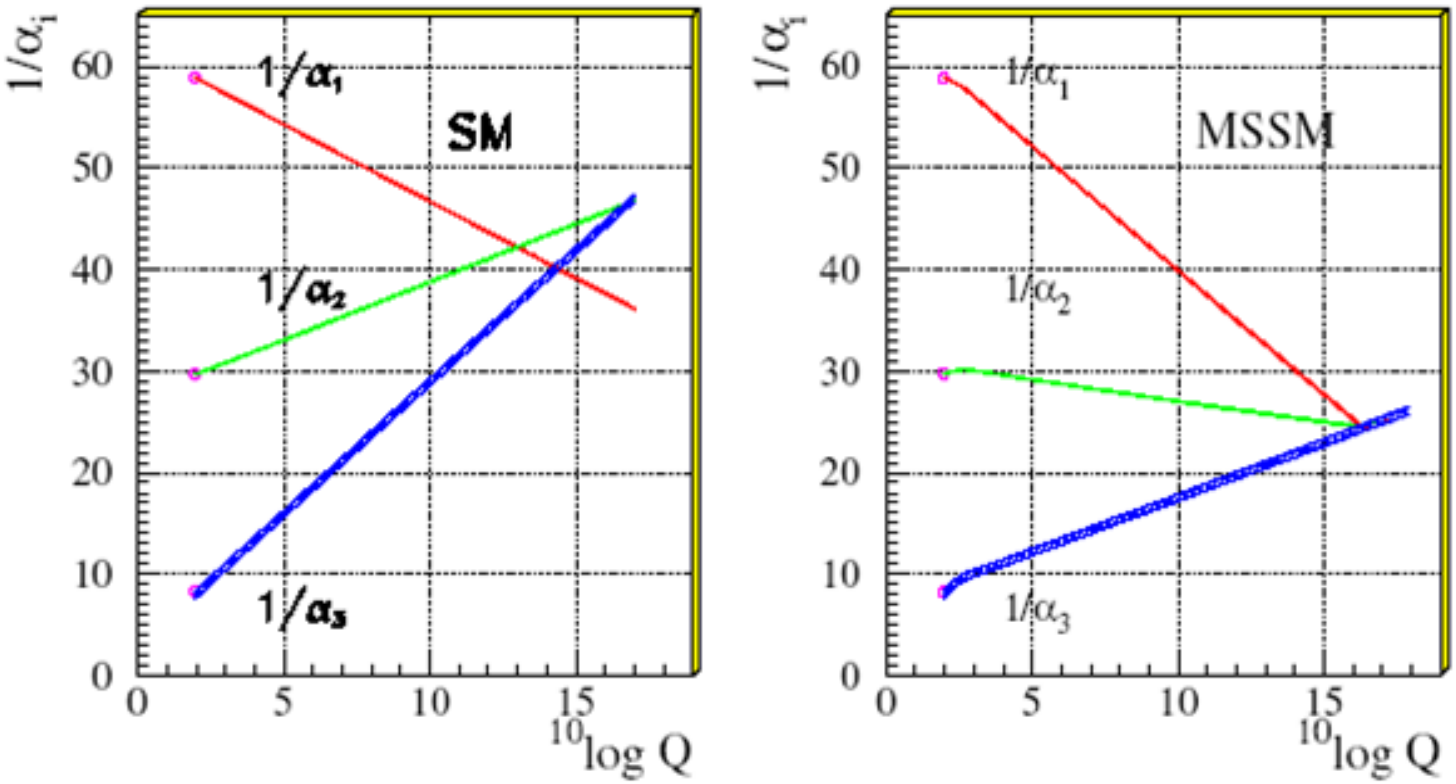
From: http://www2b.abc.net.au/science/k2/stn/newposts/5218/topic5218766.shtm

Open questions in Standard Model

Magic solution: SUPERSYMMETRY

What is origin of mass?	Radiative electroweak symmetry breaking
What is origin of dark matter?	Lightest SUSY particle (LSP)
Why 3 different gauge groups?	Unified group broken at lower energies
Why 3 different coupling constants?	Gauge couplings unified at high energy
Why so large mass differences in third generation?	Yukawa couplings unified at high energy
Why do neutrinos have mass at all?	Larger groups require right-handed neutrinos. Mass suppressed by see-saw.
What to do with quadratic divergencies?	They are canceled in SUSY
Why large hierarchy between Planck scale and electroweak scale?	Connected by radiative corrections in Supersymmetry
Why quark charges 1/3(2/3) of lepton charges?	Connected in unified theories

Precise measurements of couplings at LEP-> Unification in SUSY

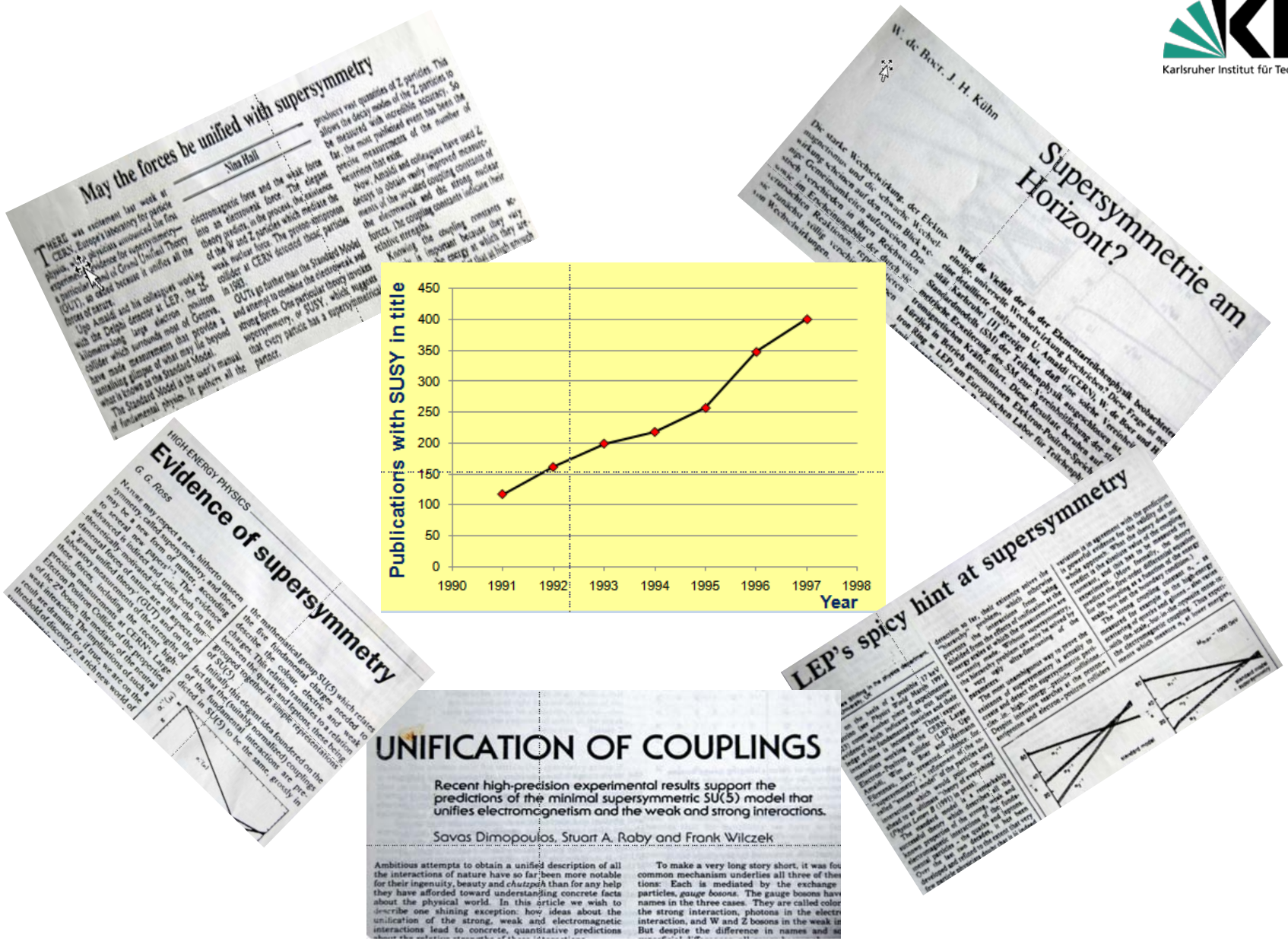


U. Amaldi, W. de Boer, H. Fürstenau, PL B260(1991)

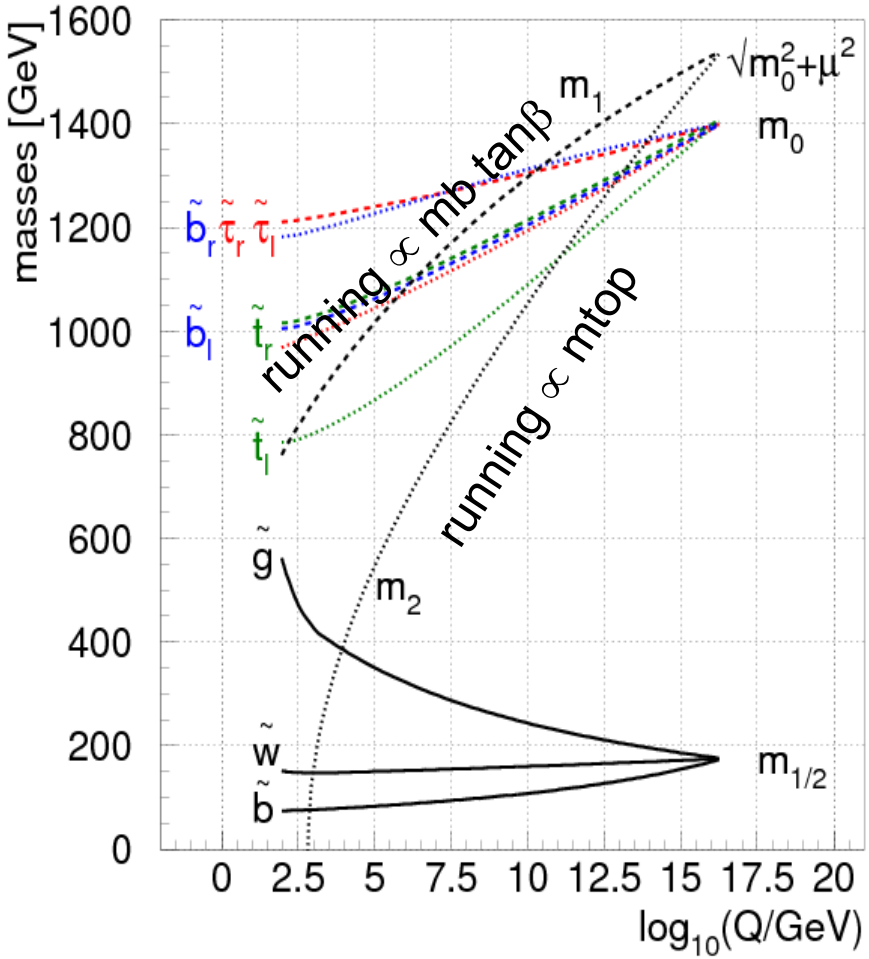
$\alpha_1, \alpha_2, \alpha_3$ coupling constants of electromagnetic –, weak–, and strong interactions

$1/\alpha_i \propto \log Q^2$ due to radiative corrections (LO)

On the 1000+ citation list..



Constrained Minimal Supersymmetric Model (MSSM)



Mass unification at GUT scale:
m_0 for scalars
$m_{1/2}$ für S=1/2 gauginos
m_1,m_2 for Higgs

Lightest Supersymmetric Particle =LSP =Neutralino (≈Photino ≈ S=1/2 Photon)

m_2 <0 by radiative corr. ∝ mtop
m_2 <0 at electroweak scale for 140<mtop<200 GeV.
BINGO, mtop predicted by SUSY BEFORE observation
mtop = 171 ± 1.3 GeV

So SUSY connects, MGUT, mtop and m_Z correctly and predicts Higgs mechanism with lightest Higgs around 120 GeV (and it fits LEP electroweak data)

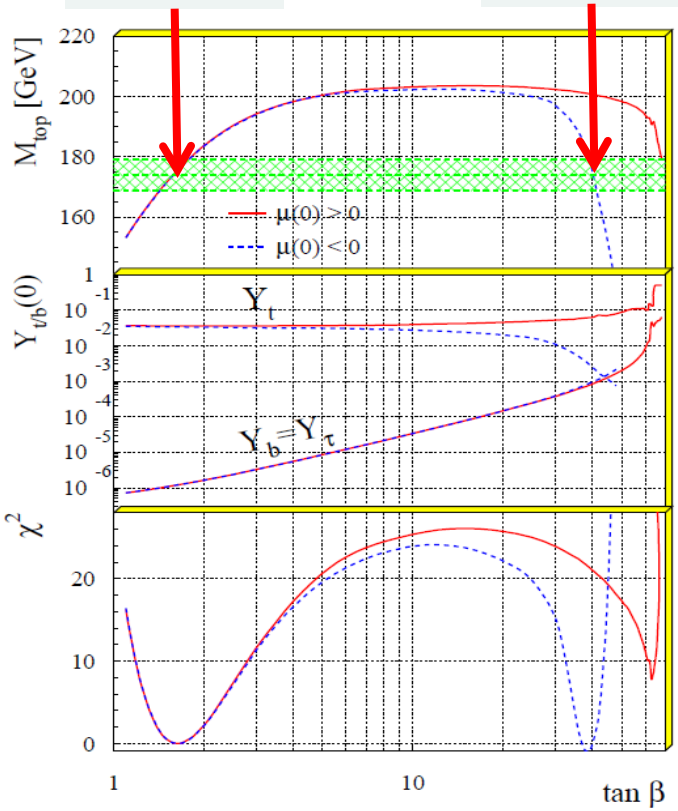
Phenomenology studied together with Dmitri

Top constraint

2 solutions:

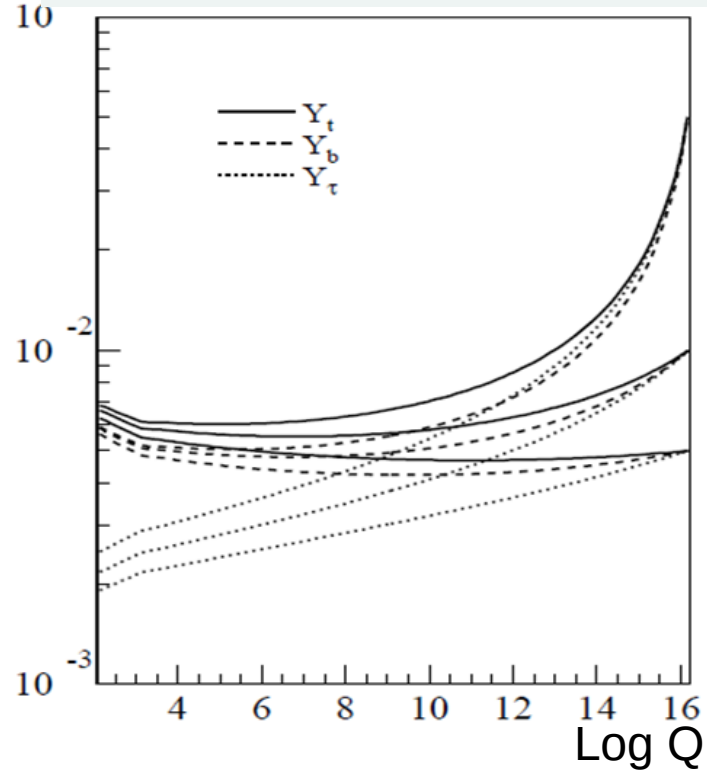
low tanβ

high tanβ



Triple unification at large tanβ

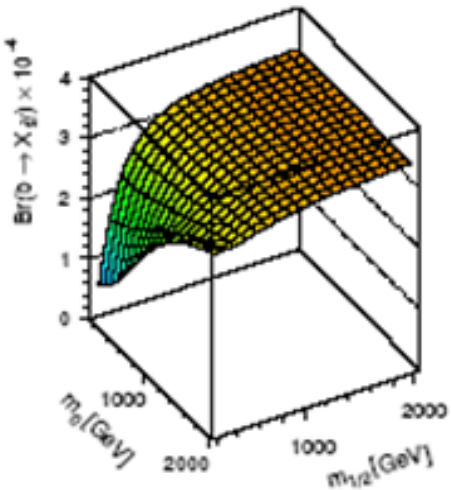
Quasi-fixed endpoints->
In SUSY mtop, mb,mtau indep.
of initial GUT conditions

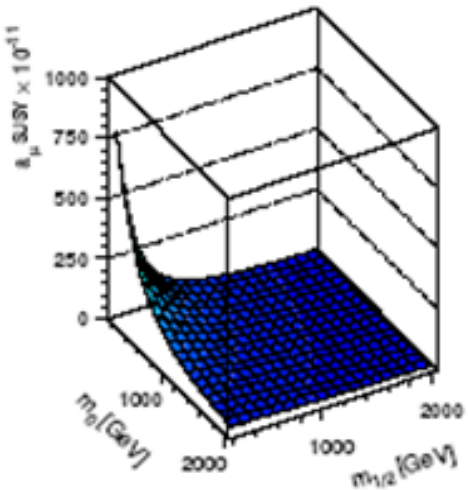


dB,Grimm,Kazakov,Gladyshev, PLB, hep-ph/9805378v3

10 years ago…

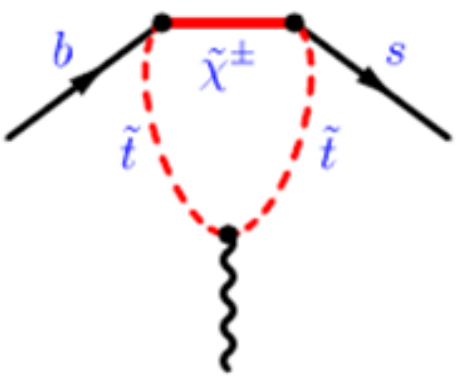
WdB, M.~Huber, C. Sander and D.I Kazakov,
A Global Fit To g-2 and bsgamma In The CMSSM,,
PLB 515 (2001) 283.

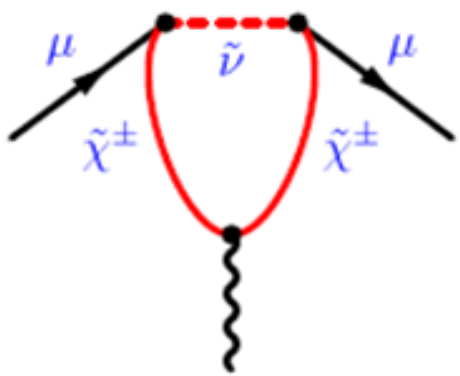




However, it was recently suggested that in the theoretical calculation one should use the running c-quark mass in the ratio m_c/m_b, which reduces this ratio from 0.29 to 0.22 [14]. The SM value for $b \to X_s\gamma$ increases from $(3.35 \pm 0.30) \times 10^{-4}$ to $(3.73 \pm 0.30) \times 10^{-4}$ in this case. This value is 1.7σ above the most recent world average of $(2.96 \pm 0.46) \times 10^{-4}$, which is the average from CLEO $((2.85 \pm 0.35_{\rm stat} \pm 0.22_{\rm sys}) \times 10^{-4})$ [15], ALEPH $((3.11 \pm 0.80_{\rm stat} \pm 0.72_{\rm sys}) \times 10^{-4})$ [16] and BELLE

$BR(b \to X_s\gamma) = (2.96 \pm 0.46) \times 10^{-4}$ [15–17] and $\Delta a_\mu = (43 \pm 16) \times 10^{-10}$ [1], which shows once





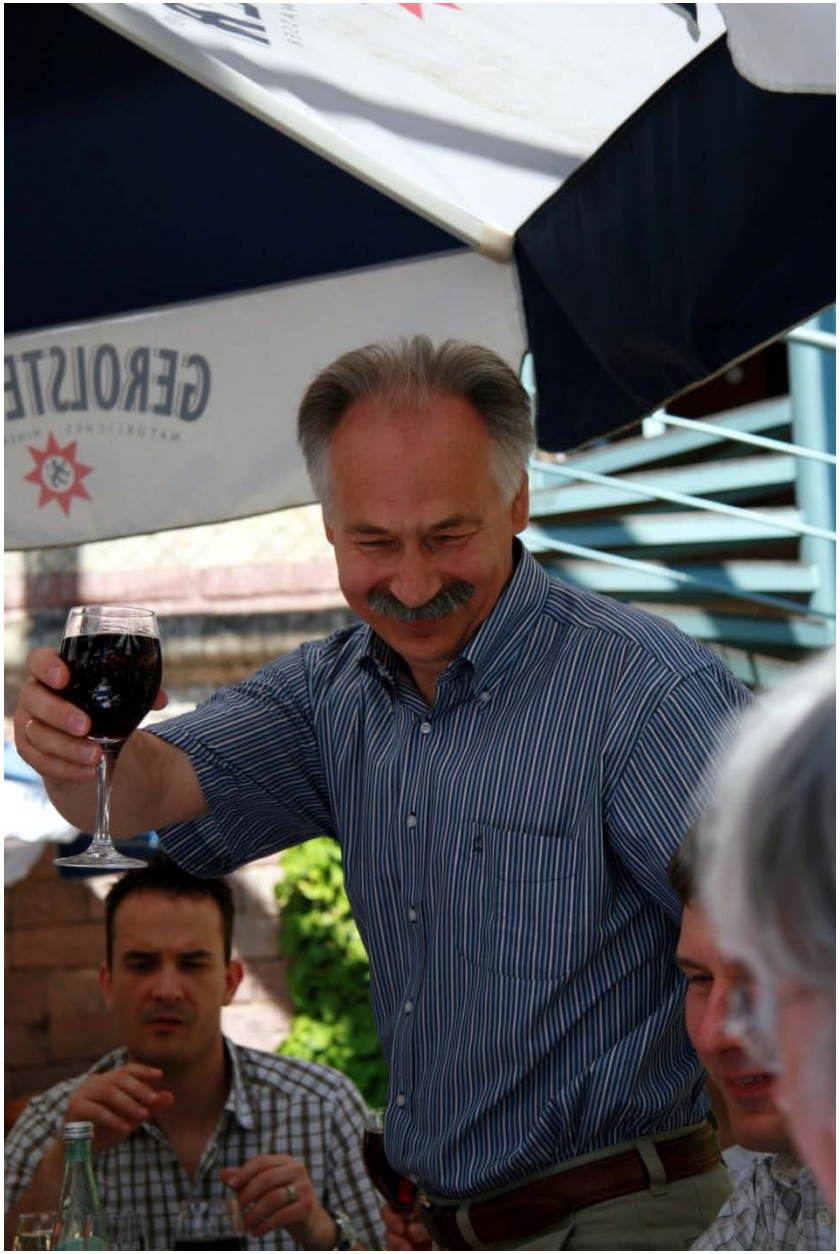
b->sγ 2001	b->sγ 2011
SM: $3.73.10^{-4}$	SM: $3.15(23).10^{-4}$
EXP: $2.96.10^{-4}$	EXP: $3.55(24).10^{-4}$

2001: b→sγ <SM, as expected for μ>0 from g-2 and A_0=0
2011: : b→sγ >SM -> tension

Dubna SUSY Conf. 2001

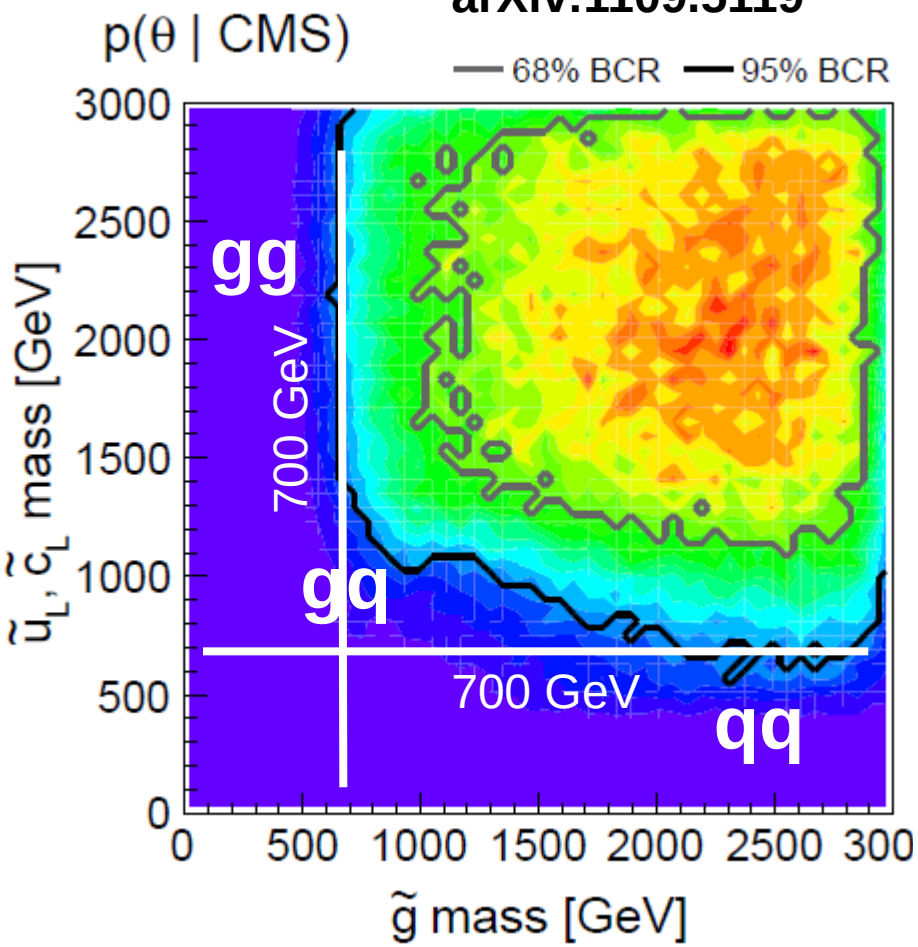
Dubna SUSY Conf. 2001

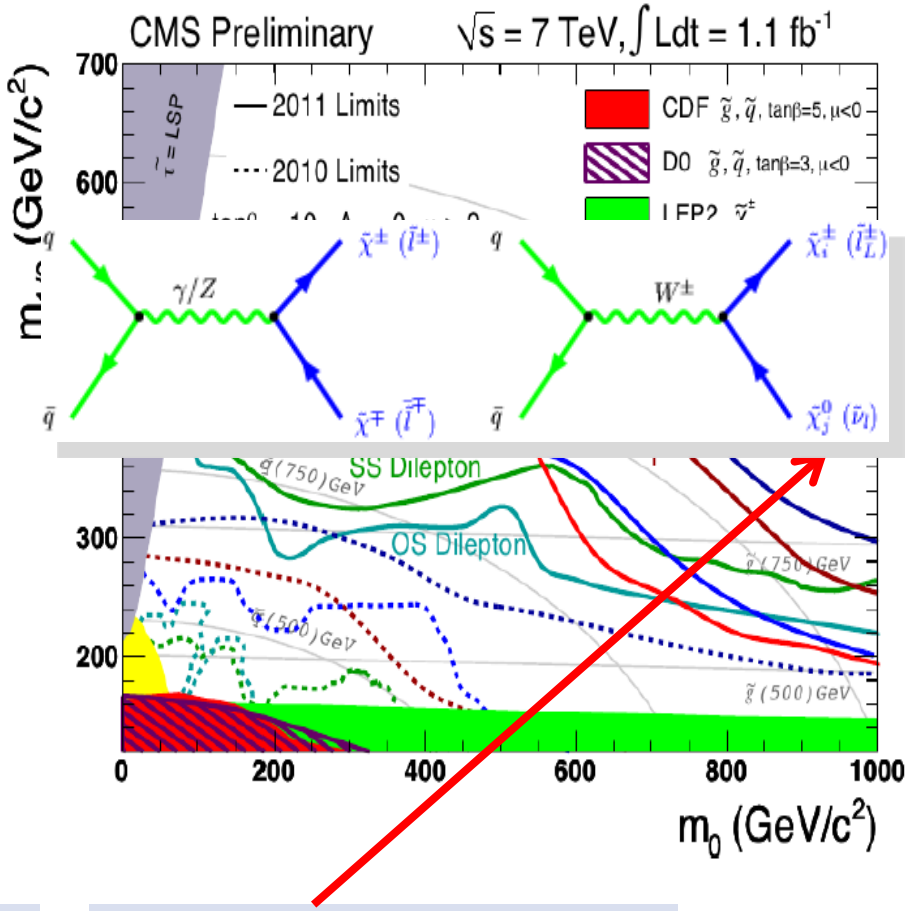
Visiting KARLSRUHE



CMS limits on SUSY parameter space

arXiv:1109.5119

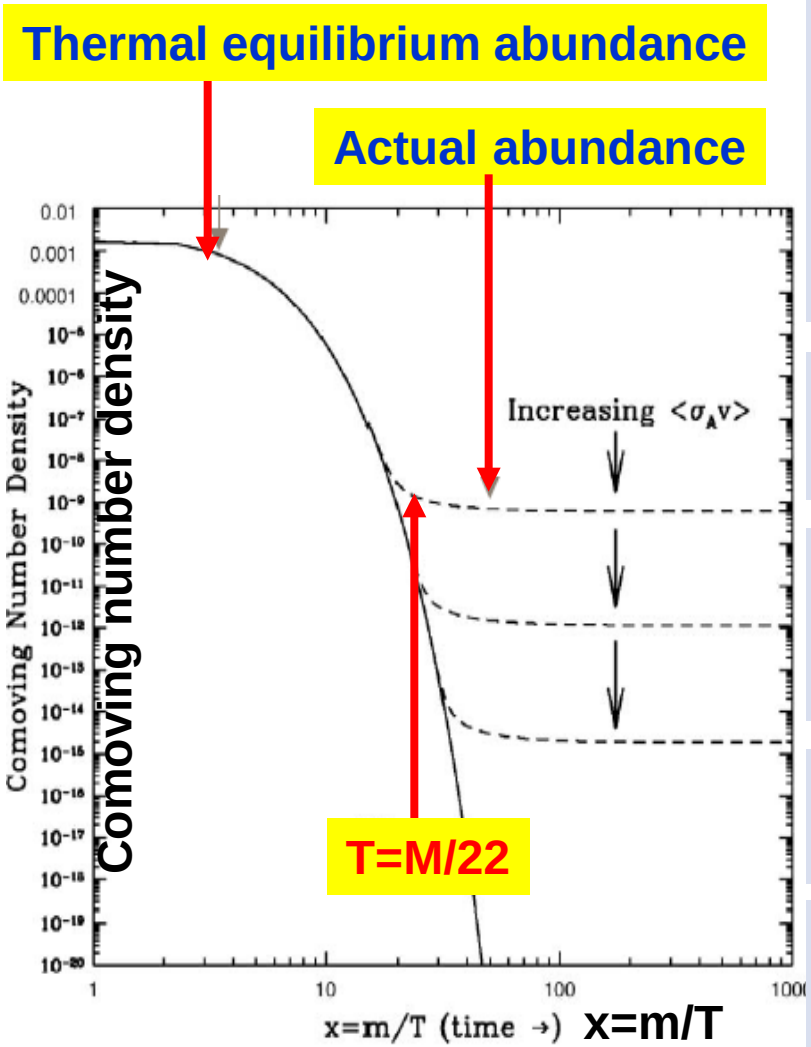




squark and gluino masses above around 700 GeV at 95% CL

Electroweak production dominates (pp->χχ)

Strongest constraint from cosmology: WIMP annihilation cross section



T>>M: $f+\bar{f}\to M+\bar{M}$; $M+M\to f+\bar{f}$
T<M: $M+\bar{M}\to f+\bar{f}$
T=M/22: M decoupled, stable density (when annihilation rate ≅ expansion-rate, i.e. $\Gamma=\langle\sigma v\rangle n_\chi(x_{fr}) \cong H(x_{fr})$!)

WMAP -> $\Omega h^2=0.113\pm0.009$ -> $\langle\sigma v\rangle=2.10^{-26}$ cm^3/s

DM increases in Galaxies: ≈1 WIMP/coffee cup ≈10^5 $\langle\rho\rangle$. DMA ($\propto\rho^2$) restarts again..

Annihilation into lighter particles, like quarks and leptons -> π_0's -> Gammas!

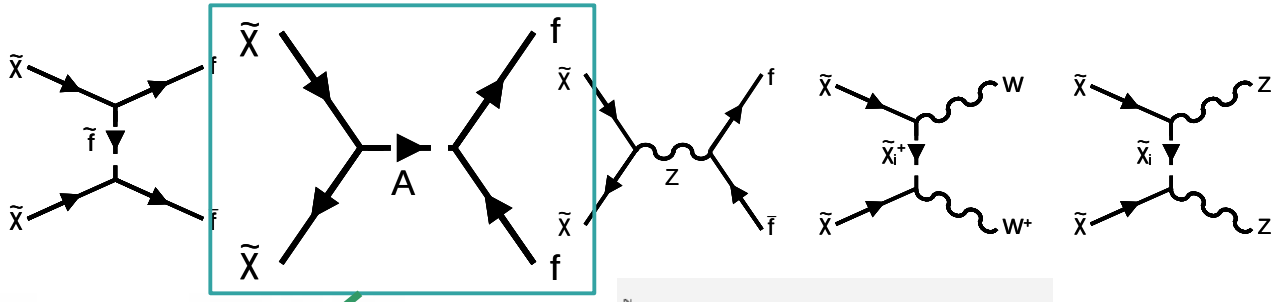
Only assumption in this analysis: WIMP = THERMAL RELIC!

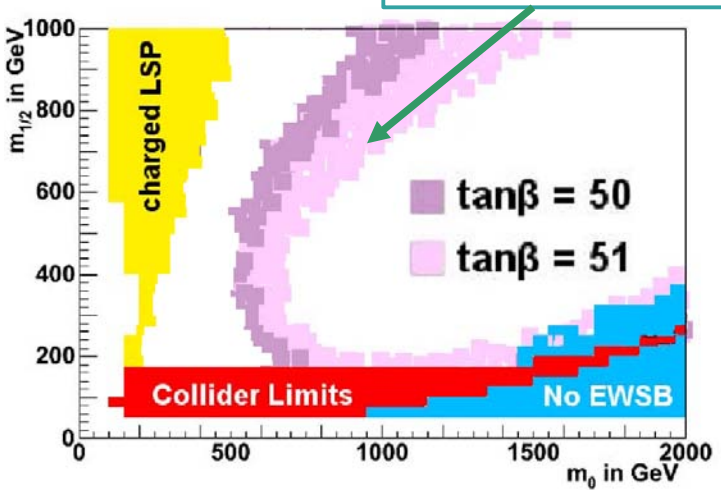
Gary Steigmann

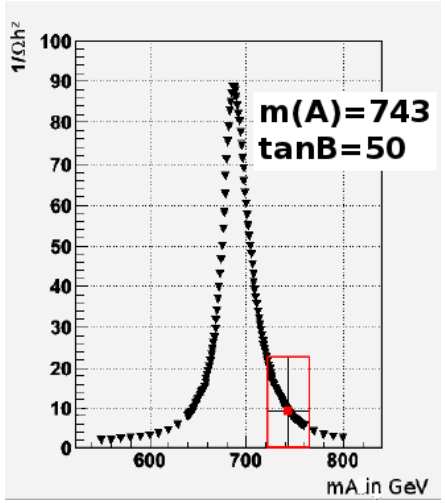
Relic Density Constraint determines tanβ !

arXiv:1008.2150

Problem: for excluded $m_{\tilde{q}}$ first diagram too small. Last 3 diagrams also small → can get correct relic density by m_A s-channel annihilation







$$\langle \sigma v \rangle \propto \frac{\tan\beta^2}{m_A^4}$$

$$\Rightarrow m_A \propto 2m_\chi \propto m_{1/2}$$

m_A can be tuned with tanβ for any $m_{1/2}$ → tanβ ≈ 50 (see next slide)

Relic Density Constraint – Dependence on tanβ

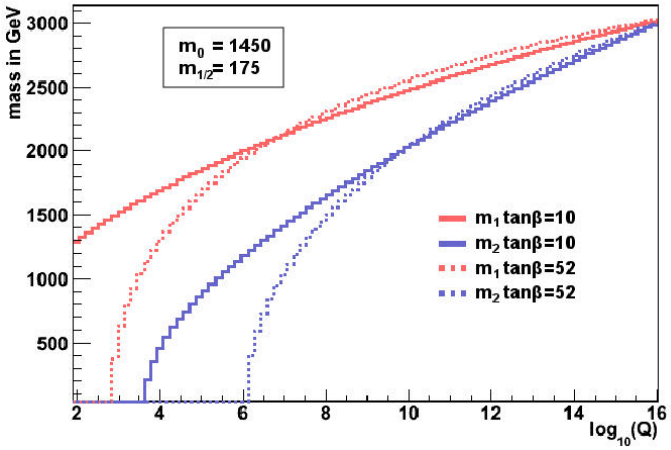
$$V_{tree}(H_1,H_2)=m_1^2|H_1|^2+m_2^2|H_2|^2-m_3^2(H_1H_2+h.c.)+\frac{g^2+g'^2}{8}\left(|H_1|^2-|H_2|^2\right)^2+\frac{g^2}{2}|H_1^+H_2^-|^2$$

$\boxed{m_A^2=m_1^2+m_2^2}$ (Tree Level)

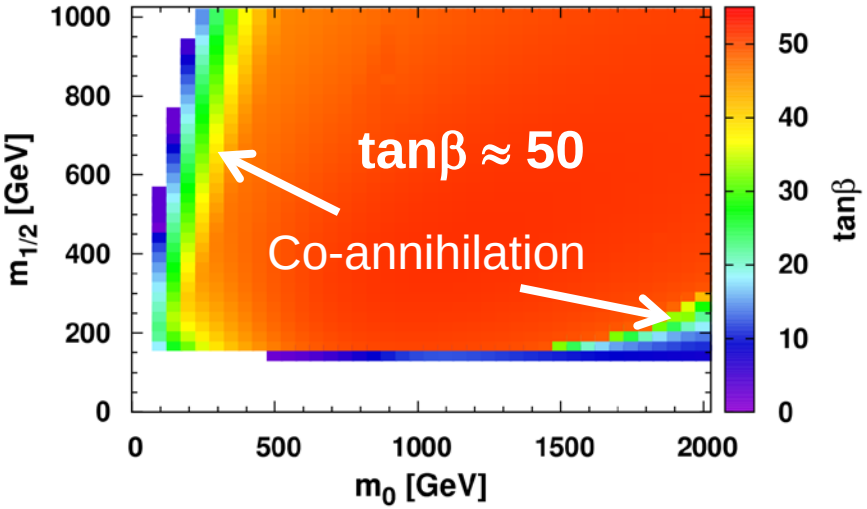
m_1^2 running ∝ mtop

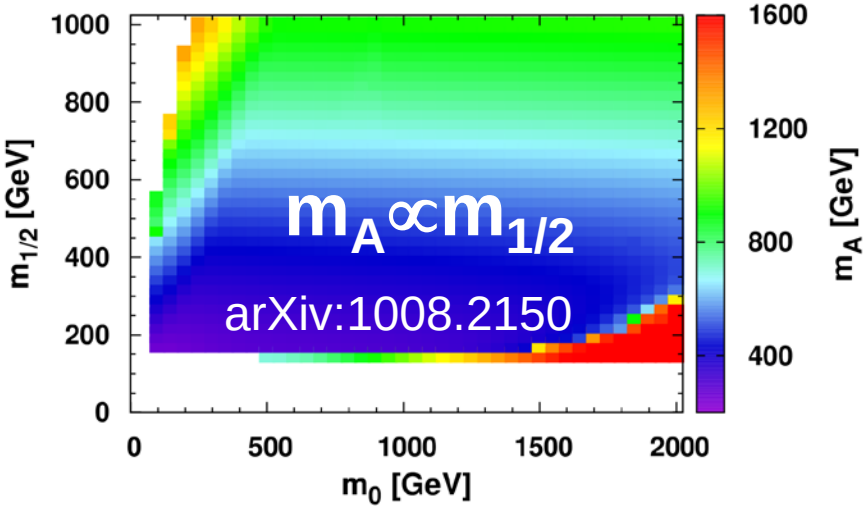
m_2^2 running ∝ mb tan β

→ small m_A for tanβ= $m_t/m_b \approx 50$

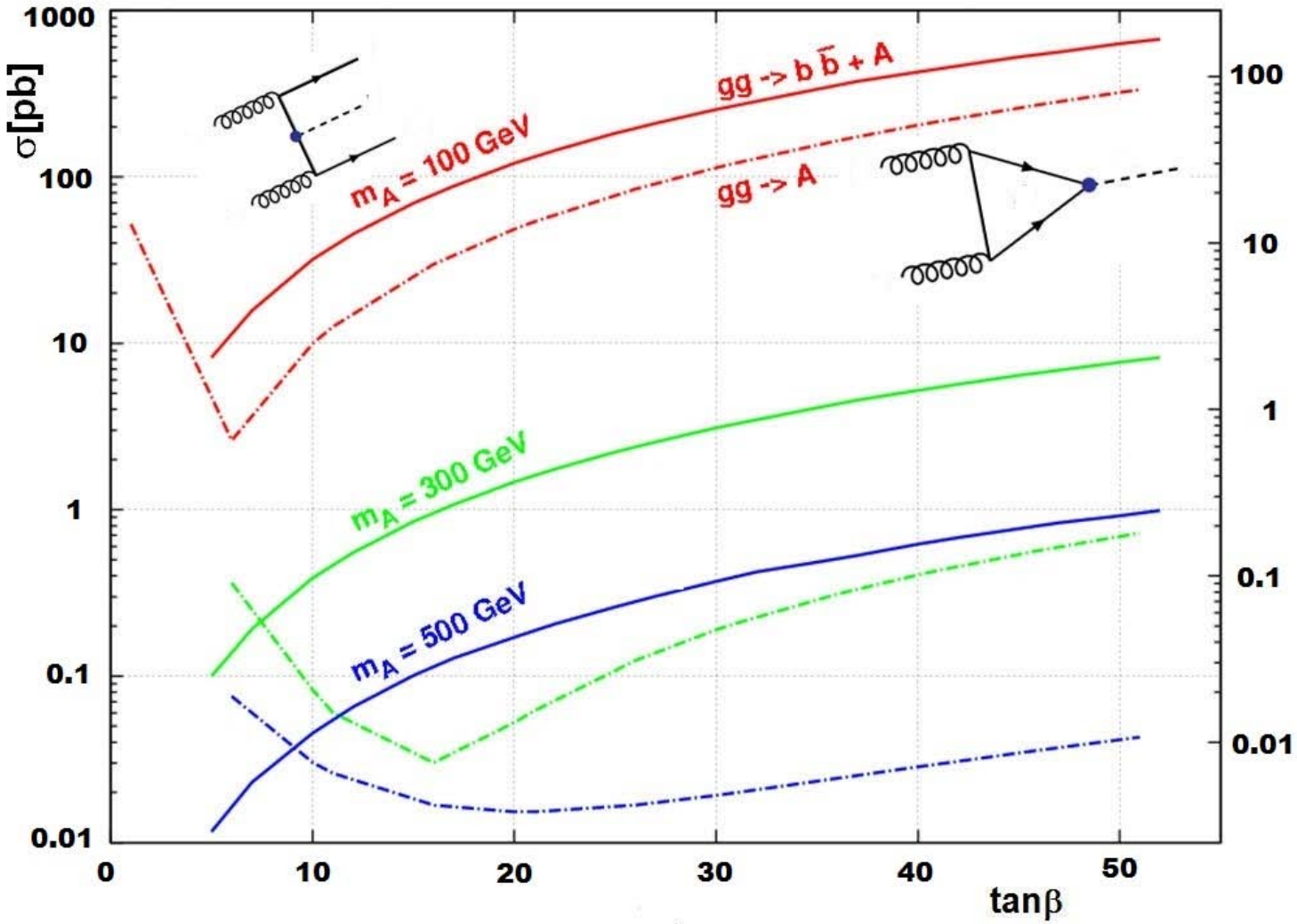


Fit of Ωh^2 determines m_A and tanβ



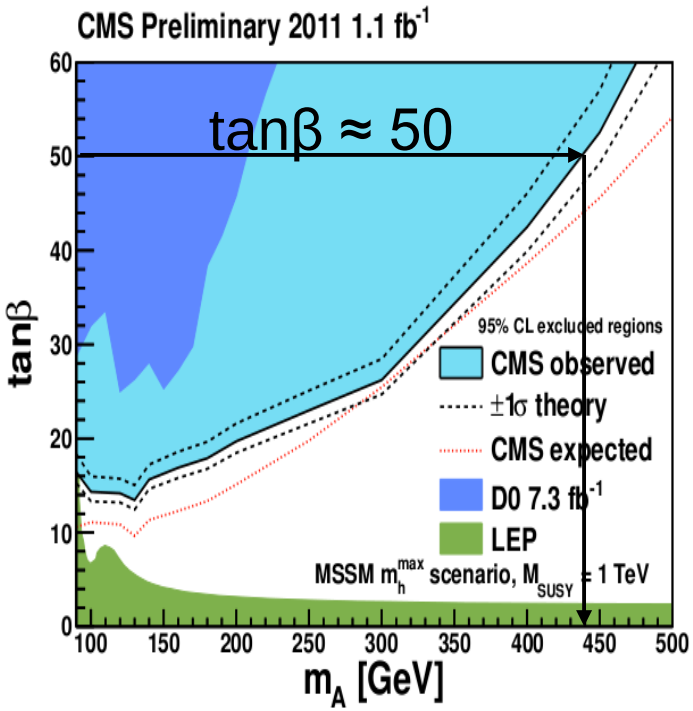


m_A cross sections $\propto \tan\beta^2$



Beskidt, dB , Kazakov,1008.2150, PLB 2011

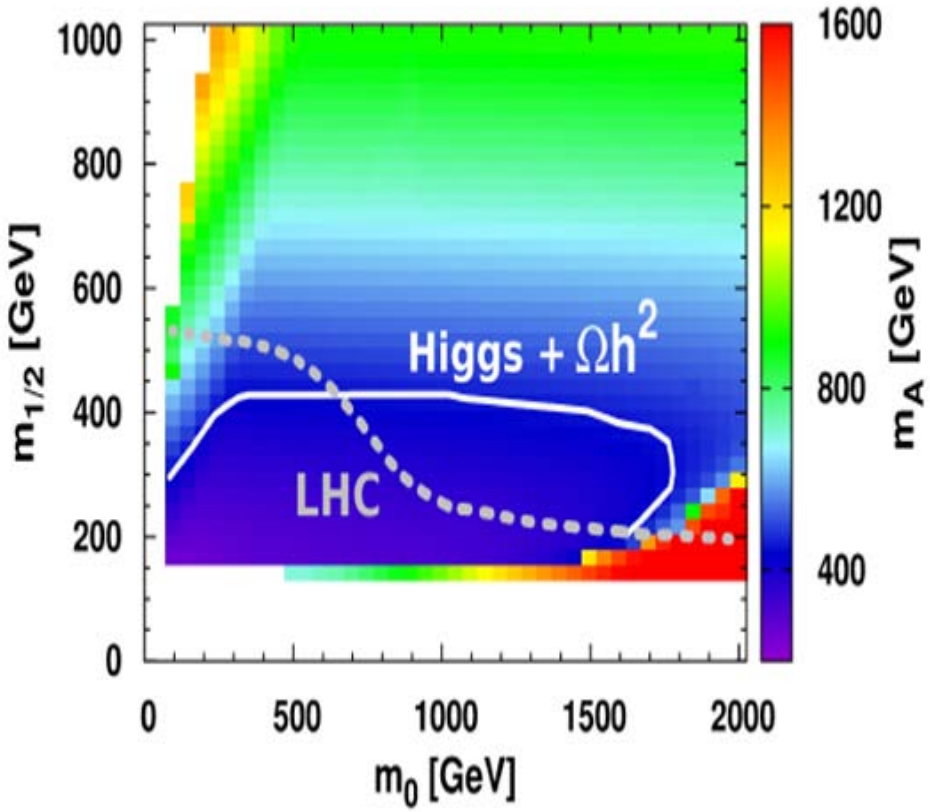
What about Higgs m_A limit?



(CMS PAS HIG-11-009)
Atlas similar

For tanβ ≈ 50
m_A > 440 GeV

arXiv:1109.6775



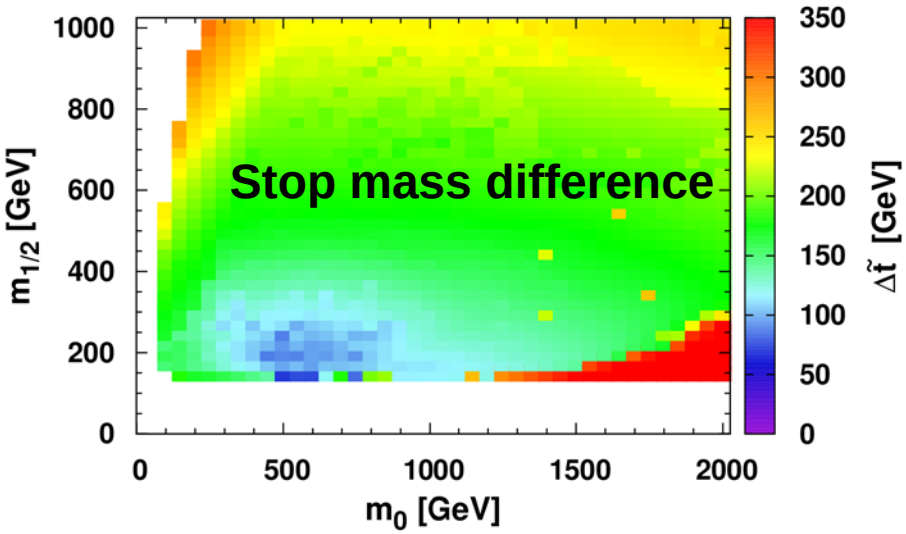
$B_s \to \mu\mu$ depends on $\tan^6\beta$ *and* A_0

arXiv:hep-ph/0203069v2

$$Br[B_s \to \mu^+\mu^-] = \frac{2\tau_B M_B^5}{64\pi} f_{B_s}^2 \sqrt{1-\frac{4m_l^2}{M_B^2}} \left[\left(1-\frac{4m_l^2}{M_B^2}\right)\left|\frac{(C_S-C_S')}{(m_b+m_s)}\right|^2 + \left|\frac{(C_P-C_P')}{(m_b+m_s)} + 2\frac{m_\mu}{M_{B_s}^2}(C_A-C_A')\right|^2\right]$$

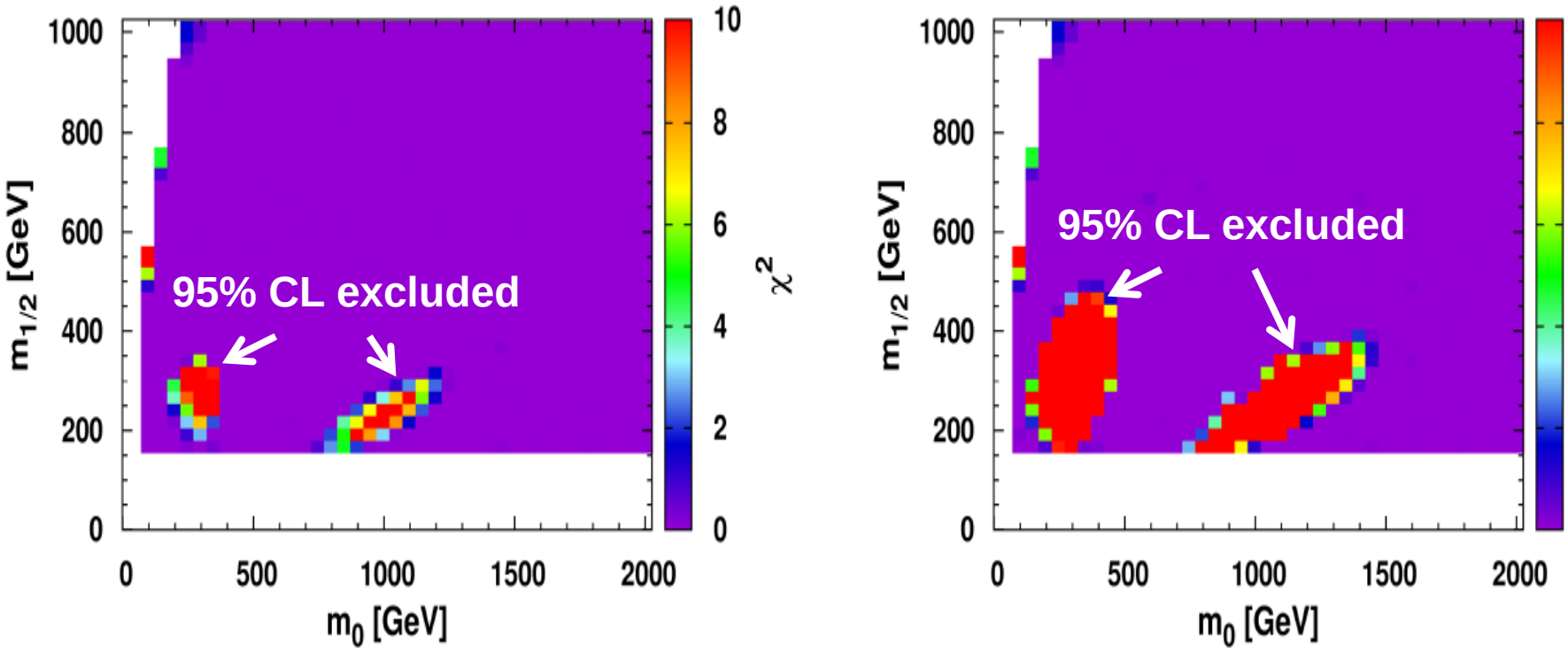
$$C_S \simeq \frac{G_F\alpha}{\sqrt{2}\pi} V_{tb}V_{ts}^* \left(\frac{\tan^3\beta}{4\sin^2\theta_W}\right)\left(\frac{m_b m_\mu m_t \mu}{M_W^2 M_A^2}\right)\frac{\sin 2\theta_{\tilde{t}}}{2}\left(\frac{m_{\tilde{t}_1}^2 \log\left[\frac{m_{\tilde{t}_1}^2}{\mu^2}\right]}{\mu^2 - m_{\tilde{t}_1}^2} - \frac{m_{\tilde{t}_2}^2 \log\left[\frac{m_{\tilde{t}_2}^2}{\mu^2}\right]}{\mu^2 - m_{\tilde{t}_2}^2}\right)$$

arXiv:1109.6775



Becomes small, if $\tilde{t}_1 \approx \tilde{t}_2$
can be achieved by adjusting A_t,
till mixing term ~ $(A_t - \mu/\tan\beta)$
becomes small.
Important only for light SUSY masses (see blue region)

If both, A_0 *and* tanβ, varied, little exclusion from Bs->μ μ



B_s<1.1 10^{-8}

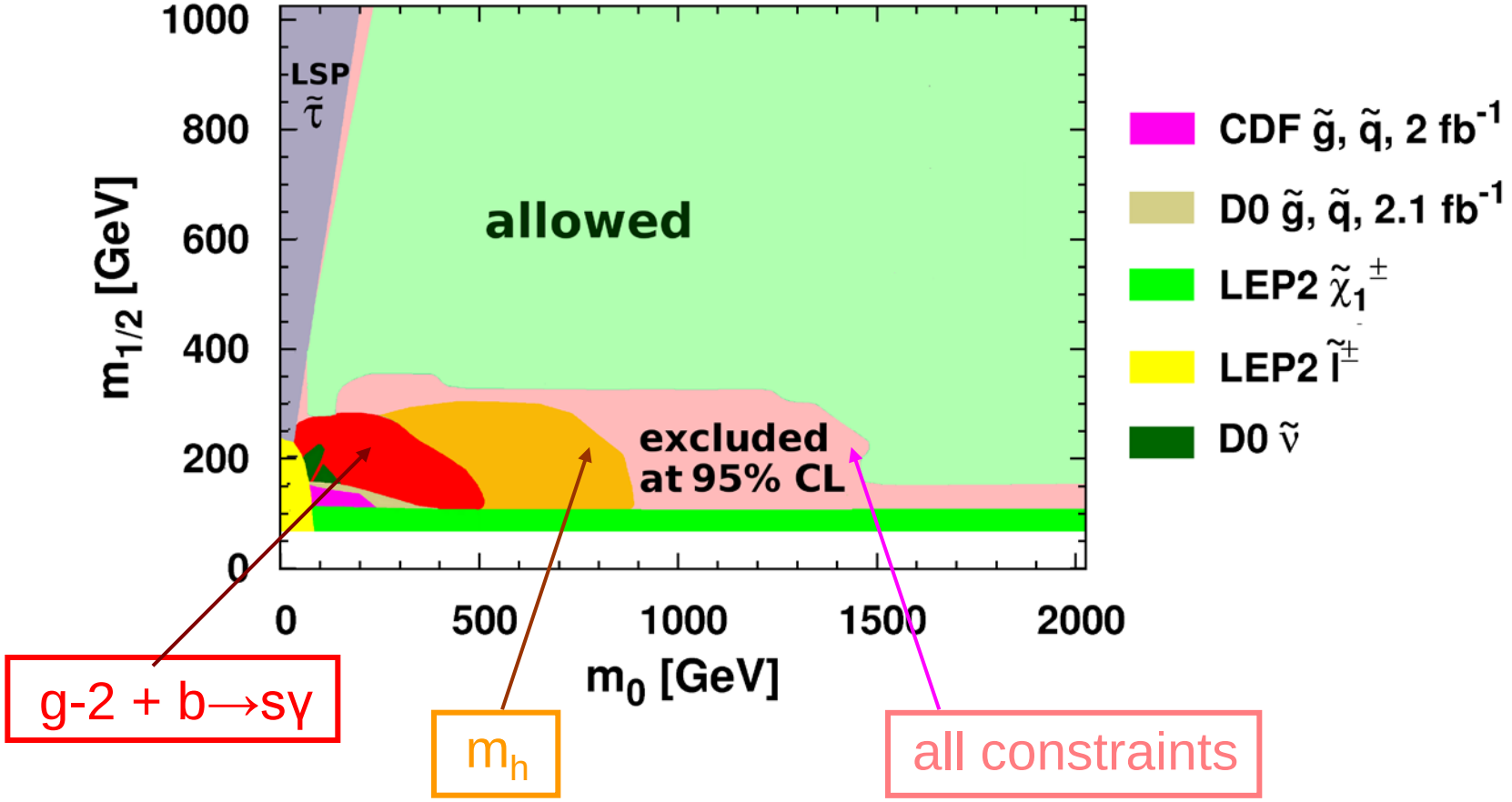
arXiv:1109.6775

Hypothetical limit:
B_s<0.66 10^{-9} (2x SM)

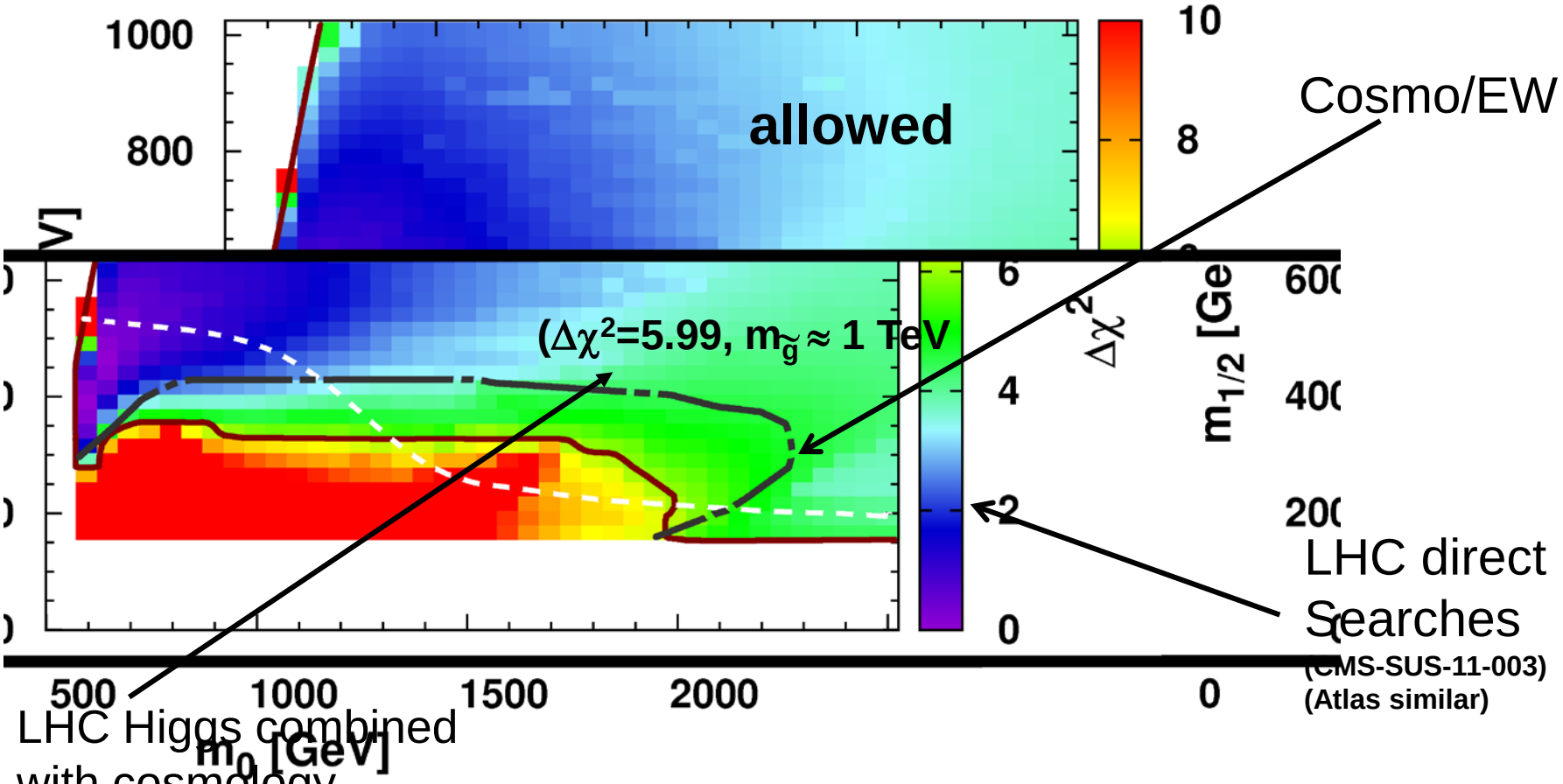
Limits from Bs->μμ smaller than limits from direct searches/cosmology

95% CL exclusion from cosmology/EW

- Allowed parameter space (95% CL contour) in the m_0-$m_{1/2}$ plane including all constraints

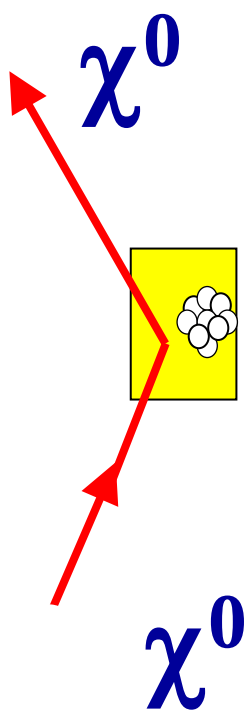


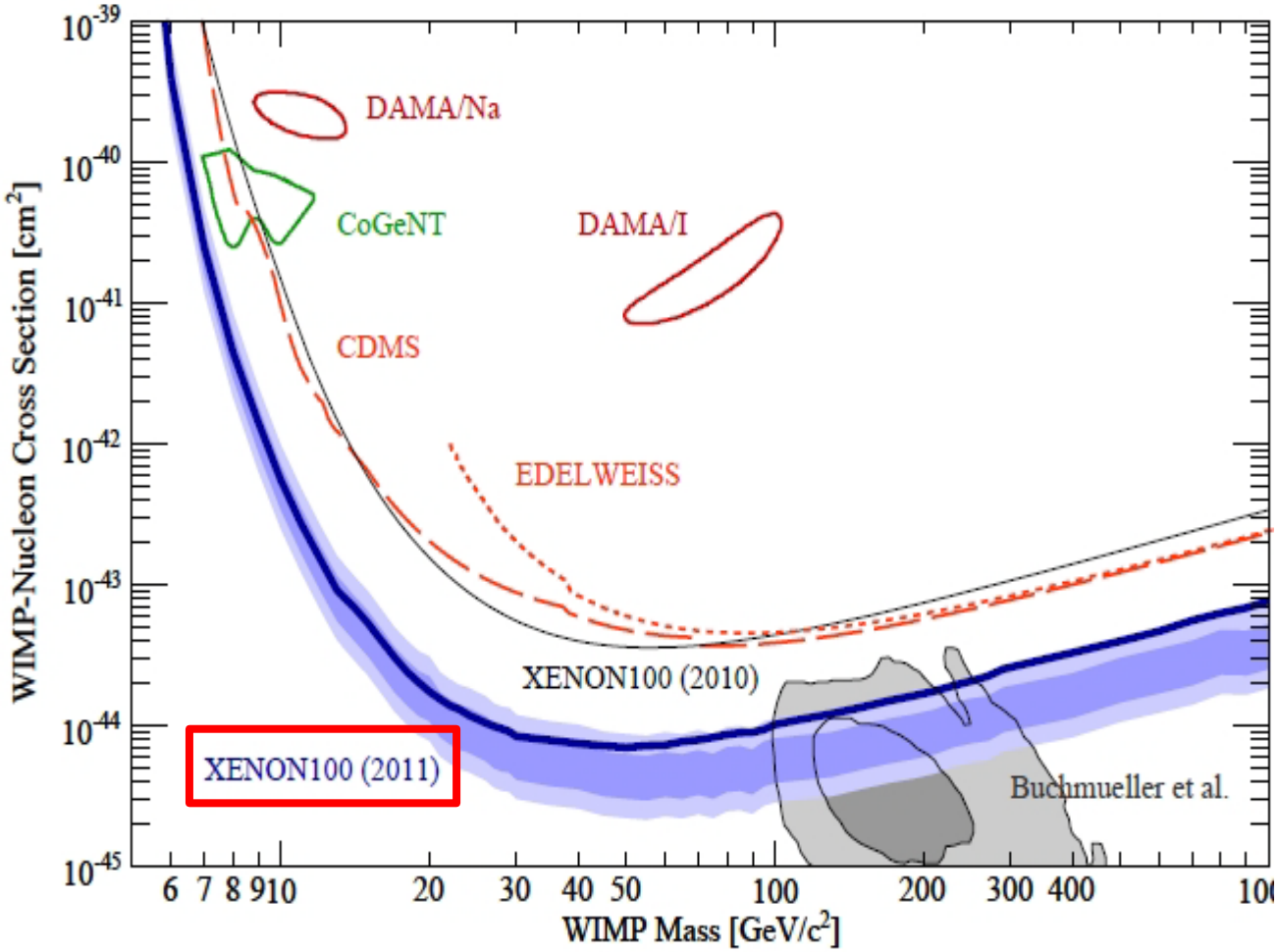
95% C.L. exclusion contours in 2011



LHC Higgs combined
with cosmology
arXiv:1109.6775

Direct Detection of WIMPs





Experimental limit has uncertainties from assumptions on halo clumpiness, rotation
Theoretical prediction has uncertainties on nuclear form factors (factor 5-10)

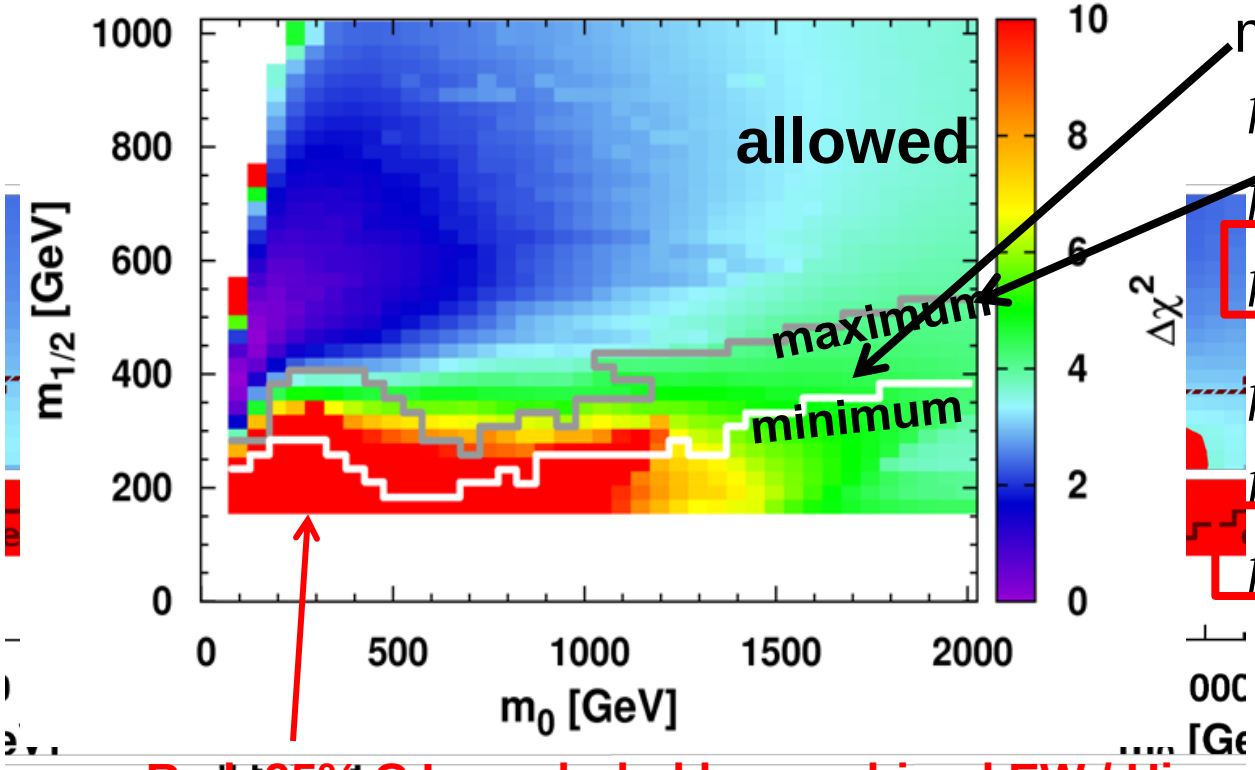
Including Direct Dark Matter Search from Xenon-100 arXiv:1104.2549

Problem: χN scattering cross sections depends on form factors

Lattice has strange quark content in nucleus similar to light quarks (arXiv:0806.4744v3)

To be conservative use the smaller form factor-> excluded region small!

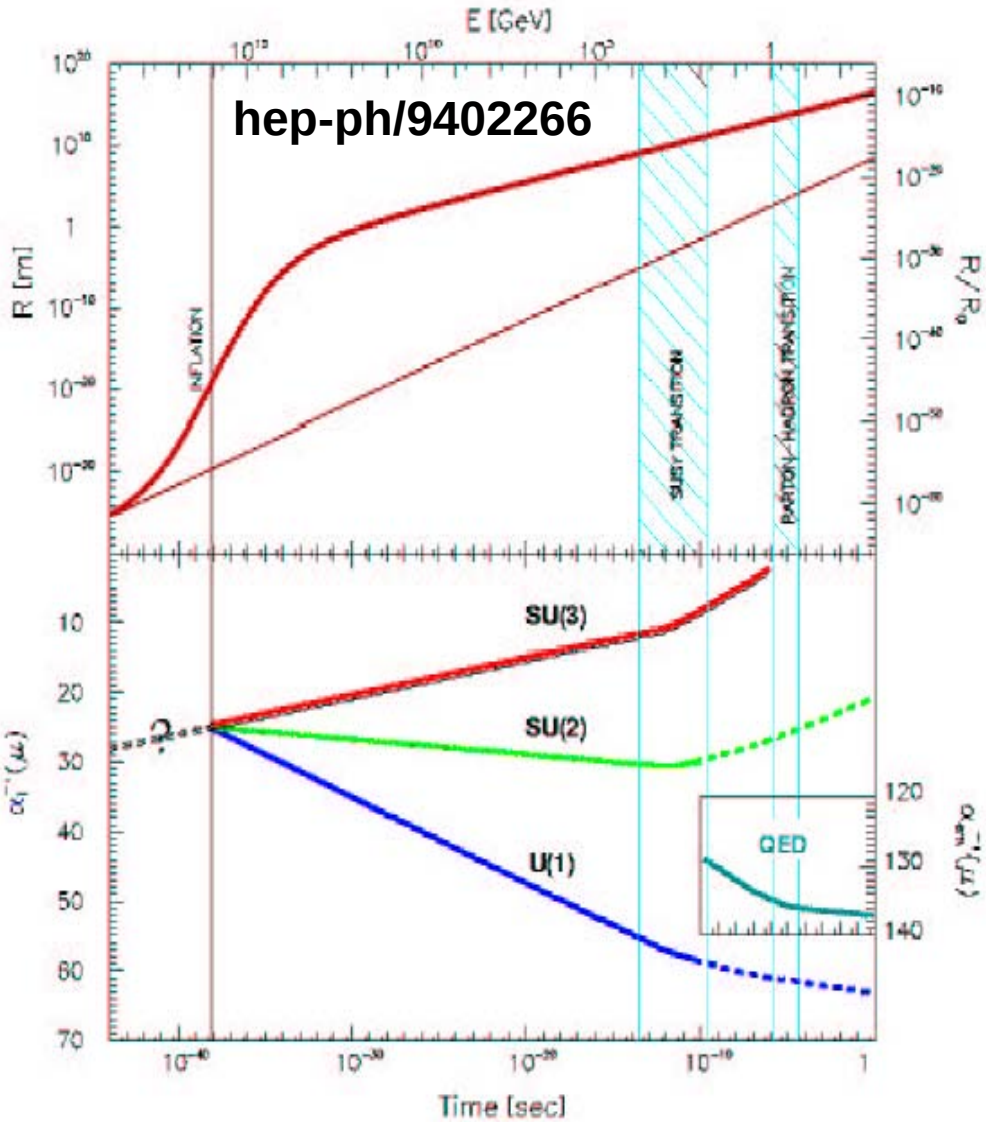
arXiv:0803.2360v2



minimum	**maximum**
$f_u^p = 0.02;$	$f_u^p = 0.023;$
$f_d^p = 0.026;$	$f_d^p = 0.033;$
$f_s^p = 0.02;$	$f_s^p = 0.26;$
$f_u^n = 0.014;$	$f_u^n = 0.018;$
$f_d^p = 0.036;$	$f_d^p = 0.042;$
$f_s^p = 0.02;$	$f_s^p = 0.26;$

Red=95% C.L. excluded by combined EW / Higgs limits

Supersymmetry in Particle Physics and Cosmology



Possible evolution of the universe with GUT scale breaking into SU3xSU2xU1 after 10^{-38} s -> Inflation

freeze-out of SUSY after few ps

freeze-out of electroweak interactions after few μs.


χ^0
$\chi^\pm$
χ^0
$\tilde{g}$
$\tilde{q}$
$\bar{\tilde{q}}$
Happy Birthday